Renewable and Sustainable Energy Reviews 16 (2012) 6879–6887

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Letter to the Editor

# Study on electrical energy and prospective electricity generation from renewable sources in Australia

ARTICLE INFO

*Keywords:*
Power grid
Renewable energy
Forecasting
Wind data
Solar insolation/irradiation
Economic model

ABSTRACT

Nowadays renewable sources are being used as clean sources to generate electricity and to reduce the dependency on fossil fuels. The uses of renewable sources are being increased in electricity generation and contributed to reduce the greenhouse gas emission. The function of any electrical power system is to connect everyone sufficiently, clean electric power anywhere and anytime of the country. This can be achieved through a modern power system by integrating electrical energy from clean renewable sources into the nation's electric grid to enhance reliability, efficiency and security of the power system. The paper on the status of review the driving force of the generation of renewable energy and proposing electrical energy generation from renewable sources to be ensured at least 20% of total energy of Australia. This paper has been studied the existing electricity generation capacity of Australia from renewable and non-renewable sources. Optimal electricity generation from renewable sources has been examined. The environmental impact of electricity generation from renewable sources has been considered. Under this paper the yearly average wind data of past 20 years and above for some meteorological stations of Australia have been used. The prospective electricity generation from wind turbines and solar photovoltaic panels has been proposed in the paper that will increase electrical energy of the power grid of Australia. It was estimated the capital cost of prospective electricity generation farms from wind and solar PV sources.



## 1. Introduction

The renewable sources are described as green and clean energy forms of energy because of their minimal environmental impact compared to fossil fuels. The advantage of the renewable sources includes their inability to produce carbon based warming and polluting agents into the atmosphere. Moreover the operating cost of electricity generation from renewable sources is not only less than fossil sources but also environment friendly. There are many sites with superior solar incidence and wind data which have less pronounced seasonal variations [1]. For this reason electricity generation from renewable sources are being rapidly increased in many sites of the world. The renewable energy converters are designing to the newest standards to integrate with the modern electrical grid, contributing sustainable power to maintain our daily life, ensuring the delivery of safe, securing and affordable energy. Due to the shortage of energy supply all over the world, the pressures on resources and the enormous power losses in energy delivery for the low efficiency of the current power grid are increasing. Owing to the growing electricity demand and user's increasing requirements, a new sort of power system of environment friendly, economic, high efficiency, safety and reliability has been a destination of engineers in power industry [2,3]. Australia has access to a range of high quality renewable energy sources those are being used for electricity generations in small scale as well as in large scale and by integrating this energy into the power grid is helping to enhance efficiency and reliability of power system [4,5]. For this reason, Australia sees the resources of renewable energy as feasible sources of primary energy in the mid term as well as long term to generate electricity. Australia has a plan of replacement for aging infrastructure to take advantage of new technologies and the future network, not only to meet the continuing growth in peak electricity consumption but also to cope with a fundamental change in the delivery of electricity services in a carbon constrained environment. Like as Europe, USA and other renewable energy developed countries, Australia can set to grow the contribution from renewables, distributed and micro generation. The renewable sources are wind and solar which can be used in electricity generation in small as well as large scale, although the intermittent nature of these sources are a concern as they are required to be supported by more manageable or predictable sources [6]. The government has a range of existing initiatives to support widespread renewable energy in Australia. Australia has a plan to generate 20% of its total electricity supply from renewable sources by 2020. On the other hand, the 'ZCA2020 stationary energy plan' proposes 100% electricity generation from renewable sources by 2020 [1]. Australia has an abundance of solar, wind and other clean energy sources. Driving innovation in clean technologies is an important element of the clean energy future plan of Australia. Many researchers are involved to generate electricity from renewable sources and endeavoured to increase efficiency of the power system. This paper has been studied the existing electricity generation of Australia and compared the growth of different sources of electrical energy. The paper has been examined the prospective solar and wind energy potential for a specific area of Australia. It was analysed the existing PV and wind power use and development in Australia.

## 2. Electrical energy generation in Australia

At present the rate of growth of Australia's electricity use is increased at an average rate of 1.7% per year. Due to the growing electricity demands and the user's increasing requirements for

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http://dx.doi.org/10.1016/j.rser.2012.07.015

reliability and quality, the power industry is now facing unprecedented challenges and opportunities. Australia is world's ninth largest energy producer accounting for around 2.4% world energy production. There are produced 32% energy for domestic consumption and 68% energy for export [4,5]. The electricity industry consisting of generators, transmission and distribution networks and retailers, is one of the largest industries of Australia. This paper has been studied the existing electricity generation from conventional and non-conventional sources of Australia.

### 2.1. Resources used in electricity generation of Australia

Australia is one of the richest countries in energy content terms of the world. The plentiful resources are expected to last for many decades. The quality of the resources is high as compared to overseas resources. There are different types of resources used in electricity generation.

#### 2.1.1. Coal

This source is used as main sources in generating electrical energy. The majority of coal sources are located in New South Wales, Victoria and Queensland. Australian coal represents 9% of world total.

#### 2.1.2. Gas

This source is one of the main sources used in electricity generation. These conventional gas sources located off the west and north-west coast of Australia, in New South Wales and Queensland.

#### 2.1.3. Petroleum

This resource represents a small production of the world and used in electricity generation. The majority part of Australian petroleum sources is located off the coasts of Western Australia, in Northern Territory and Victoria. Australia's oil resources are much smaller than its gas or coal resource.

#### 2.1.4. Uranium

Australia has abundant resources of uranium and it represents about 38% of total world resources. The majority of these valuable resources are located in the Northern Territory, South Australia and Western Australia.

#### 2.1.5. Renewable sources

The main sources of renewable energy used in electricity generation are bagasse, 'wood and wood waste' and hydroelectric, which combined accounted for about 87% of total renewable energy. The remainder sources of renewable energy are wind, solar and biofuels. Almost all bagasse fuelled energy production facilities located in Queensland while wind farms are most in South Australia and Victoria. The hydroelectric capacity is located mostly in New South Wales, Queensland, Tasmania and Victoria [4,5].

### 2.2. Existing electricity generation by fuel

Australia is one of the largest energy producers of the world. The abundant amount of energy resources is located inside of the earth. The energy production of Australia is dominated by coal, which accounted for 54% of total Australian energy production in energy content terms, second source is uranium in Australian fuel rankings with a share of 27% and natural gas with a share of 11% [4,5]. Crude oil and LPG represented 6% of total energy production, and renewable represented 2%. At present the electricity generation capacity of Australia is around 51.179 GW and around 2, 62,568 GW h of electricity is being generated in Australia at present which is shown in Fig. 1.

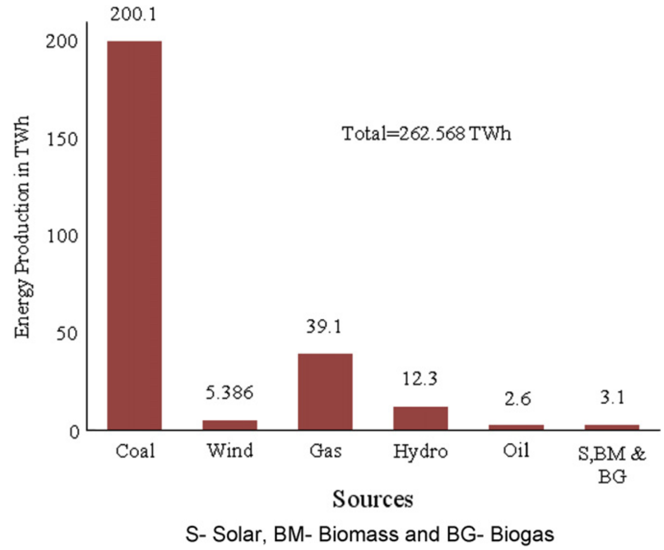


**Fig. 1.** Electricity generation of Australia in TW h by Fuel in 2011.

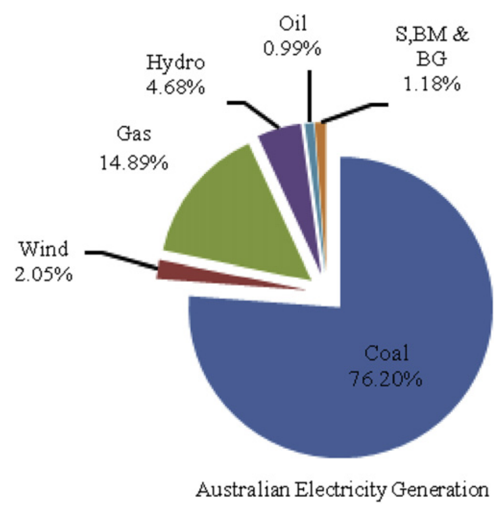


**Fig. 2.** Existing Australian electricity generation in percentage by fuel.

The majority of Australia's electricity generation is supplied by steam plants using coal or natural gas. The existing electricity generation of Australia in percent with respect to fuel is shown in Fig. 2 and it is seen that electricity generation from renewable energy sources is being contributed a little compared to other sources of energy. But due to the crisis of conventional energy resources all over the world, it is obviously to use alternate sort of energy resources which will be environment friendly. These alternate sorts of energy may be renewable sources and abundant electricity can generate from these sources that can contribute to reduce the dependence on fossil sources.

### 2.3. Existing renewable energy generation capacity

At present renewable energy is being contributed about 8.9% of Australian electrical energy generation. The renewable energy production of Australia is dominated by hydroelectricity, bagasse, 'wood and wood waste' and wind which combined accounted for around 96% of renewable energy production. Solar, biofuel and other accounted for the remainder of Australia's renewable energy production. The lists of renewable energy productions are given in Table 1 and it is seen from the table, the existing

**Table 1**
Existing renewable energy generation capacity in Australia.

| Sources of energy (MW) | SA | Vic | WA | NSW | Tas | QLD | NT | Other[a] | AUS |
|---|---|---|---|---|---|---|---|---|---|
| Bagasse | – | – | – | 43.0 | – | 377.0 | – | – | 420 |
| Biogas | 22.0 | 83.0 | 28.0 | 74.0 | 4.0 | 19.0 | 1.0 | – | 231 |
| Hydroelectricity | 4.0 | 769.0 | 32.0 | 4293.0 | 2284.0 | 667.0 | – | – | 8049 |
| Solar Energy | 1.9 | 1.2 | 0.9 | 5.1 | 0.2 | 0.5 | 1.1 | 177.0 | 188 |
| Wood waste | 10.0 | – | 6.0 | 42.0 | – | 15.0 | – | – | 73 |
| Wind Energy | 1000.0 | 458.0 | 203.0 | 226.0 | 144.0 | 12.0 | 0.1 | | 2043 |
| Biomass and biodiesel[b] | – | 34.0 | – | 3.0 | – | 4.0 | – | – | 41 |
| Ocean and geothermal | – | 0.2 | – | – | – | 0.1 | – | – | 0.3 |
| Total MW | 1038 | 1345 | 270 | 4686 | 2432 | 1095 | 2.0 | 177 | 11045 |

[a] Solar PV installations at unspecified locations.
[b] Mixed biomass feedstocks, municipal waste and black liquor.

electricity generation from renewable sources is 11,045 MW only [4,5]. At present wind and solar sources are contributing a little in generating of electricity compared to other conventional sources of Australia. With the natural advantage of Australia, plentiful electrical energy can be produced from renewable sources. Australia has many sites with better solar irradiation and wind speed as well as less pronounced seasonal variations than overseas sites. So a lot of amount of electricity can be generated from renewable sources that can contribute to increase efficiency, security and reliability of power system of Australia within short period.

### 2.4. Growth of electricity generation from renewable sources

The financial cost for the application of renewable sources is more in some cases compared to conventional sources but environmental benefits outweigh all the disadvantages. For this reason trends toward renewable energy are taking hold on a more widespread basis every day. The government of Australia provides an opportunity for energy distributors to generate localized electric power from renewable sources that allowed residential, commercial and industrial customers to self-generate and sell surplus energy back to their utilities [7–9]. So, an abundant amount of electricity can generate from these renewable sources, because of Australia is one of the areas of better solar insolation and wind data all over the world. At present, renewable sources are being used to generate electricity including hydro, biomass, wind and solar. Due to the present increasing trends toward electricity generation from wind source in overseas, Australia also plans to generate electricity in large scale from this source. Renewable energy contributes around 8.9% to Australian electricity generation, with 4.68% source from hydroelectricity as shown in Fig. 2. Wind energy has experienced strong growth over recent years and now represents 2.05% of total electricity generation of Australia [4,5]. Existing electricity generation from wind turbine and solar energy sources is shown in Fig. 3. As seen from the Fig. 3(a), some sites of Australia such as South Australia, Victoria, Western Australia are contributing to generate electricity relatively better than other territory of Australia from wind source. It is seen from the study that there are some territories of Australia those can contribute to generate electricity from wind source, although sometimes seasonal variations affect on electricity generation. Fig. 3(b) illustrates the electricity generation from solar source of Australia and it is seen that NSW is being contributed better than other territories. The solar resource of Australia is equal to the world's best and the annual average solar irradiation is greater than 6 kW h/m$^2$/day over much of the continent [1,10,11]. Electricity generation from solar source shares insufficient as compared to other sources, but this source can be used in large scale electricity generation like as other

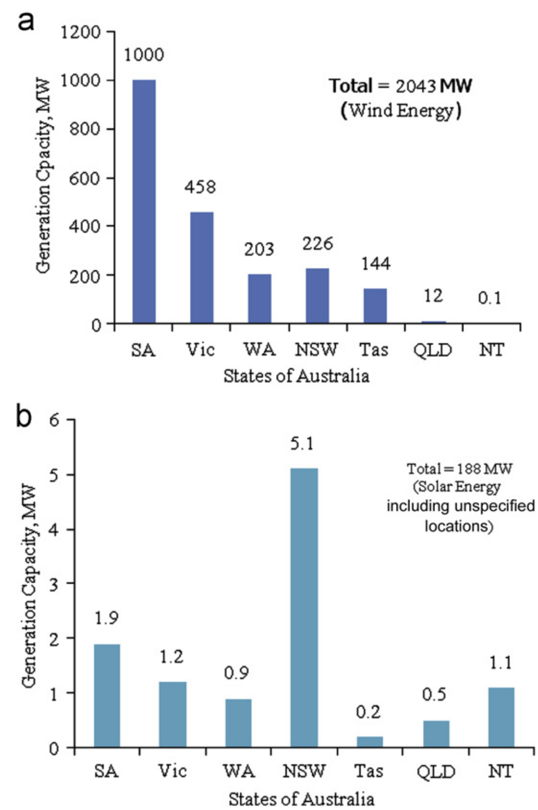


**Fig. 3.** (a) Existing wind energy generation capacity in Australia (b) Existing solar energy generation capacity in Australia.

countries of the world that can contribute to increase efficiency and reliability of the power system. Due to the superior condition of renewable sources, wind and solar PV sources can contribute in large scale electricity generation of Australia.

### 2.5. Development of renewable energy in other places of the world

Because of the extreme attention for environmental protection, both Europe and USA are working for the development of electrical power grid using renewable sources. European Union is committed to reduce its overall carbon dioxide emissions to at least 20% below 1990 levels by 2020. It has also set itself the target of increasing the share of renewable in energy use to 20% by 2020 [12–14]. Electricity is obviously of great importance for renewable in terms of e.g., solar and wind power generation. Many countries around the world are facing as the great challenges for securing access to affordable, reliable and better

renewable energy. Denmark has installed a lot of amount of individual wind generators that produce more than 20% of the Denmark total generation. France has more than 4000 MW of wind production on its system with a 2020 target of 20 GW of wind production as well as 5 GW of solar production[4,5,15]. The Federal Republic of German Government is planning in the medium-term wind turbine will be erected with a total power of 36 GW on and offshore, which would be covered around 15% of the German electricity consumption. Moreover USA, Spain, UK, Norway, China, South Korea, Japan and other countries of the worlds are facing new challenges to generate electricity from renewable sources and funding an abundant toward the establishment of large scale commercial projects [2,3,16–23].

## 3. Prospective electricity generation from renewable sources

At present Electricity generation from renewable sources is an essential part all over the world as clean energy and the uses of renewable sources in electricity generation are increasing in day by day. It is recognized that renewable energy sources need to be a part of the energy mix for sustainable future. However, intermittent renewable energy sources such as wind and solar need to be supported with other utility generation sources. At present, the availability of these renewable sources is well below than conventional central power generation [16,24–27]. As a developed country, Australia can generate electricity in large scale from renewable sources and can contribute in reducing thousands of tonnes $CO_2$ emission each year. Among the renewable sources wind and solar energy has experienced strong growth over recent years. Electricity generation from these sources can play important role to enhance reliability and efficiency of the power system. The Federal Government has a plan to ensure renewable energy obtains a 20% share of electricity supply in Australia by 2020. As seen from the study, the 'ZCA2020 plan' proposes 40% of Australia's total estimated electricity demand of 325 TW h/year would be provided by wind power. So, 130 TW h electricity will be generated by the wind source [1,4,5]. Therefore it is anticipated that Federal Government's plan can be fulfilled by many time early of 2020. At present 262.568 TW h of electricity is being generated in Australia. So additional 42.28 TW h i.e., 4827 MW energy is required to generate from renewable sources to be ensured 20% of the country's total energy [11,28]. At present the existing ratio of generating capacity of wind and solar PV is approximately 10.87:1. So considering this ratio, it can be generated 4380 MW from wind turbines and 447 MW from solar PV sources. Among the renewable sources wind and solar PV sources can be used to generate abundant electrical energy because of the superior solar insolation and wind data in Australia. This paper considers technological solutions which are already commercially available from existing providers at a large scale [1]. The paper proposes the mix technology (solar and wind) because the renewable energy has intermittent character: the sun does not shine at night and the wind does not blow always.

### 3.1. Prospective electricity generation from wind turbines

The growing awareness about pollution and concern with environmental issues is inspiring the fundamental shift toward using renewable energy whenever it is possible. At present wind energy is the world's fastest growing energy source expanding at annual rates of between 30% and 35% [1]. There are many sites with superior wind data in Australia which have less pronounced seasonal variations compared to overseas. It is shown in the Table 1 that due to the availability of wind sources, existing capacity of electricity generation from wind source is about 2043 MW. But it is not sufficient quantity as Australia has many sites with excellent wind data for electricity generation from this source. The yearly average wind data of 20 years and above for some selected meteorological stations for the different areas of Australia are shown in Table 2 and it is seen from this table, many sites of Australia have superior wind speed those can be used to generate electricity in large scale [29–32]. The monthly average speeds at different heights $h_1$ m and $h_2$ m can be estimated using the wind formula as

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\alpha} \left(\frac{km}{hr}\right) \quad \cdots \tag{1}$$

where, $v_1$ and $v_2$ are the wind speeds and $\alpha$ is wind shear exponent. The value of $\alpha$ ranges from 0.1 to 0.4 and depends on atmospheric stability and ground roughness.

The maximum power available from the wind is

$$P = \frac{1}{2}\rho A v^3 C_p \quad \cdots \tag{2}$$

where, $\rho$ is the density of air, A is the swept area of the rotor and $C_p$ is the power coefficient. The maximum possible value of $C_p$ is 0.593 which is called Betz limit.

The yearly average seasonal wind data are shown in Table 3. The data of Table 3 show that electricity generation can be possible in abundant from wind source in the different sites of Australia each year. From Table 3, the seasonal average wind data are drawn in Fig. 4. The seasonal diagrams of Fig. 4 show that due to the intermittent nature of wind source, wind turbines do not operate at full capacity all of the time. It is seen from this table, in summer Victoria, Western Australia, New South Wales, South Australia, Tasmania and Queensland experienced highest average speed and the lowest of Northern Territory. In autumn, winter and spring, Victoria and other territory experienced highest average speed and lowest in Northern Territory. In Australia capacity factor for operating wind farms are in the range of 30%–35% [1,10,33–40]. Plentiful electricity can be generated from wind source in many sites of Australia each year. To supply 4380 MW, assuming 30% capacity factor, it is required the construction of an additional 14,600 MW of wind turbines. It is proposed that to supply 4380 MW of electricity, 7300 wind

**Table 2**
Yearly average wind data for different regions of Australia in km/h.

| | NSW | VIC | WA | SA | TAS | QLD | NT |
|---|---|---|---|---|---|---|---|
| Jan | 19.73 | 20.57 | 20.30 | 18.40 | 18.63 | 19.17 | 8.00 |
| Feb | 18.23 | 20.23 | 20.73 | 18.07 | 17.60 | 19.30 | 7.47 |
| Mar | 15.93 | 19.17 | 19.50 | 16.73 | 16.83 | 21.00 | 6.53 |
| Apr | 15.50 | 19.10 | 16.37 | 15.77 | 17.57 | 20.93 | 8.30 |
| May | 12.93 | 19.03 | 15.73 | 14.80 | 18.37 | 18.70 | 10.67 |
| Jun | 12.77 | 21.43 | 16.93 | 15.83 | 17.83 | 17.93 | 11.90 |
| Jul | 12.67 | 22.00 | 17.37 | 16.43 | 18.30 | 17.40 | 10.57 |
| Aug | 15.23 | 22.50 | 16.63 | 17.57 | 19.23 | 18.23 | 9.00 |
| Sep | 17.90 | 22.90 | 18.00 | 19.57 | 20.97 | 18.83 | 7.77 |
| Oct | 19.13 | 21.97 | 18.83 | 19.67 | 19.37 | 18.97 | 8.07 |
| Nov | 19.23 | 20.63 | 20.20 | 18.93 | 18.90 | 17.73 | 7.23 |
| Dec | 19.17 | 20.37 | 19.57 | 18.77 | 20.03 | 17.63 | 7.57 |

**Table 3**
The yearly average seasonal wind data for different regions of Australia in km/h.

| | NSW | VIC | WA | SA | TAS | QLD | NT |
|---|---|---|---|---|---|---|---|
| Summer | 19.05 | 20.23 | 20.12 | 18.08 | 18.75 | 18.70 | 7.68 |
| Autumn | 14.73 | 19.10 | 17.20 | 15.77 | 17.59 | 20.21 | 8.50 |
| Winter | 13.56 | 21.98 | 16.97 | 16.61 | 18.45 | 17.85 | 10.47 |
| Spring | 18.75 | 21.83 | 19.01 | 19.39 | 19.75 | 18.51 | 7.69 |

turbines 2 MW/turbine to be installed at geographically suitable areas of SA, Victoria, WA, NSW, Tasmania, QLD and NT. It is seen from the study, the majority of wind turbines rating are between 1.3 MW and 2.3 MW in different sites of Australia. The proposed installations of wind turbines help to ensure renewable energy obtains a 20% share of electricity supply in Australia by 2020. At present Australia has one of the highest commercially exploitable wind resources per capita in the world. There are conductive the wind speeds in Australia to the exploitation of the wind resources for electrical power and many superior wind sites are already have grid coverage is an added benefit.

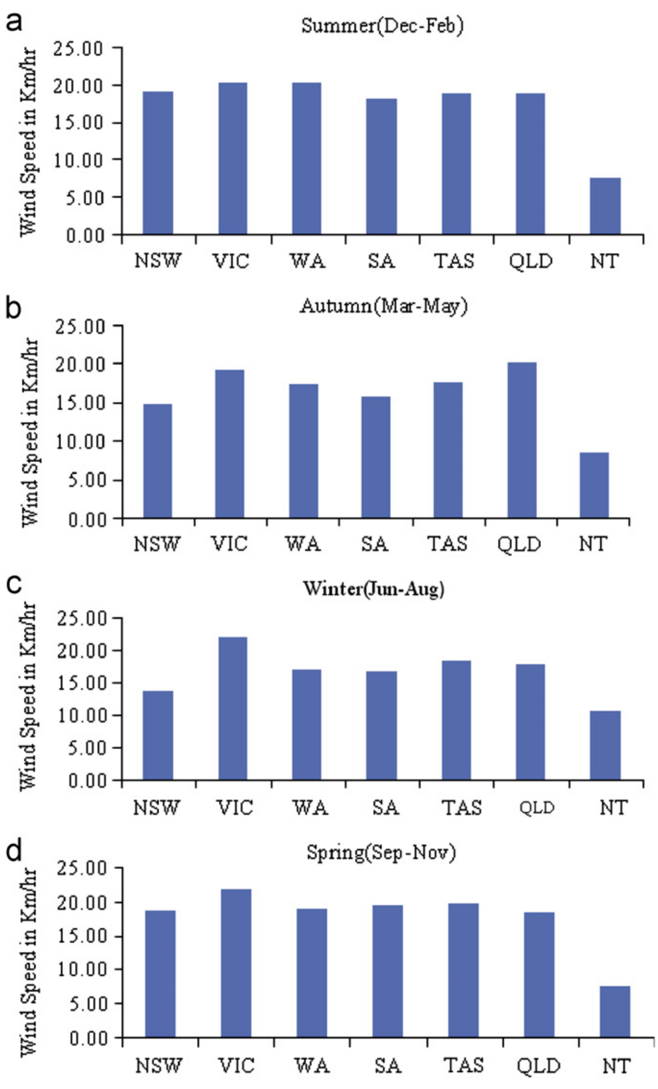


**Fig. 4.** (a) The seasonal average wind data of Australia for summer (b) The seasonal average wind data of Australia for autumn (c) The seasonal average wind data of Australia for winter (d) The seasonal average wind data of Australia for spring.

### 3.2. *Prospective electricity generation from solar PV*

As a clean energy, solar PV source is an important source in generating electrical energy. It is seen from the study, the quality of Australia's solar resource is equal to the world's best and the annual average solar insolation is greater than 6 kW h/m$^2$/day. It is found from the study, there are many sites with superior solar irradiation and less pronounced seasonal variation in Australia than other overseas sites. A comparison of monthly solar resources in KW h/m$^2$/day for some areas of the world is shown in Table 4 [1] and it is seen from this table, the excellent solar characteristic of Australia's sites and this source will be able to generate economic solar power in Australia. At present concentrating photovoltaic solar (CPV) technologies are being used in large scale electricity generation in Australia, which are fast increasing the efficiency and reducing the cost of installation. The electricity generation from solar PV panels is very important as the technologies used in electricity generation are very simple and it can be installed anywhere due to the availability of solar insolation. Usually capacity factor for operating PV farms are in the range of 11%–23% [41–43]. To supply 447 MW electrical powers, assuming 20% capacity factor, it is required to install of additional 2235 MW of PV panels. It is proposed to supply 447 MW of electricity from 10,000; 224 kw/PV panel to be installed at geographically suitable areas of SA, Victoria, WA, NSW, Tasmania, QLD and NT. So additional total 4827 MW electrical power can add to the electrical power grid of Australia that can ensure to increase electricity generation up to 20% (existing 8.9%, additional 11.1%) of the country's total energy by 2020. Total electricity generation including proposed wind turbine and solar PV panels is shown in Fig. 5 and electricity generation in percentage by fuel including proposed renewable energy sources is shown in Fig. 6.

### 3.3. *Economic model for proposed electricity generation from wind turbines and PV panels*

This paper has been studied the cost of installations of wind turbines and solar PV panels for the different areas of Australia.

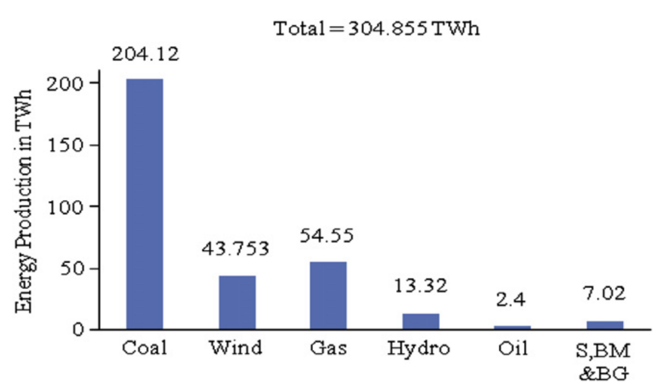


**Fig. 5.** Electricity generation in TW h by fuel including proposed renewable energy sources.

**Table 4**
A comparison of monthly solar data in kW h/m$^2$/day in Australia, Spain and USA.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mojave desert, USA | 5.29 | 5.62 | 7.03 | 7.95 | 8.32 | 8.55 | 7.87 | 7.50 | 7.03 | 6.37 | 5.90 | 5.25 | 6.90 |
| Seville, Spain | 4.62 | 5.30 | 6.14 | 6.24 | 6.79 | 8.32 | 9.26 | 8.42 | 6.74 | 4.92 | 4.26 | 3.94 | 6.25 |
| Longreach, Australia | 6.63 | 6.36 | 6.63 | 6.54 | 6.38 | 6.61 | 7.05 | 7.30 | 7.54 | 7.05 | 7.18 | 7.13 | 6.87 |
| Carnarvon, Australia | 9.63 | 8.80 | 8.27 | 7.13 | 6.42 | 6.33 | 6.66 | 7.72 | 8.78 | 9.57 | 9.98 | 8.25 | 8.26 |
| Mildura, Australia | 7.52 | 7.10 | 6.71 | 5.76 | 4.56 | 4.13 | 4.25 | 4.92 | 5.62 | 6.49 | 6.89 | 7.17 | 5.92 |

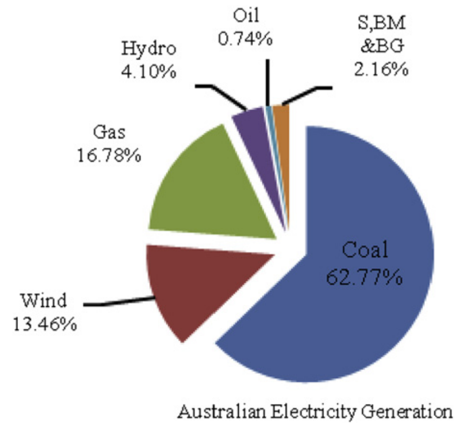


**Fig. 6.** Australian electricity generation in percentage by fuel including proposed renewable energy sources.

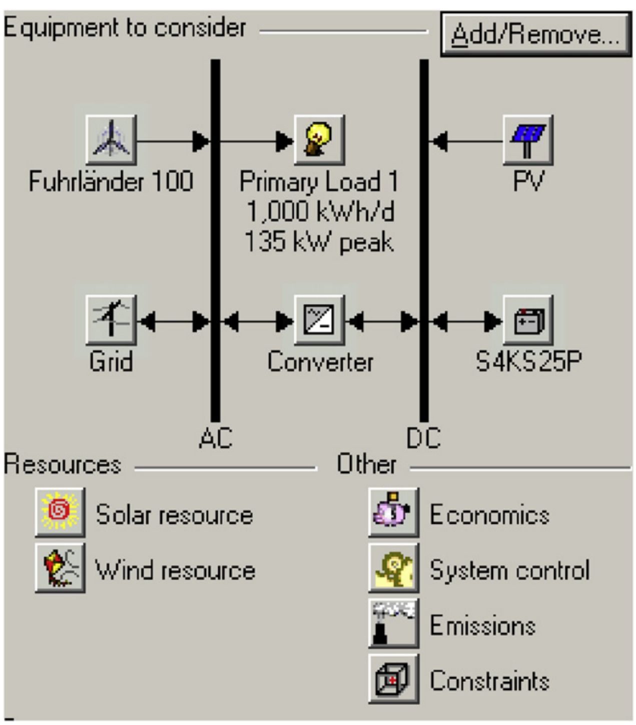


**Fig. 7.** Schematic diagram of electrical system consisting load and components used in HOMER software.

A large or small scale solar and wind technologies play a valuable role in reducing grid electricity demand. At present the cost of electricity from distributed solar PV is very higher relatively to the cost of conventional and other sources of Australia. But this cost of solar PV per kW h is decreasing in every year. It is important to mention that the larger the installed PV system, the lower the cost per kW. Small scale solar PV panels are being played an important role in reducing electricity demand. The average increase of solar PV sources is about 48% per annum. From the study it is assumed that the existing average capital cost for solar PV panels farms is 3.59 million $AU/MW [44]. As to supply 447 MW electrical power, assuming 20% capacity factor, it is required to install of additional 2235 MW of PV panels and total investment for the proposed 2235 MW of solar panels is estimated at 8023.65 million $AU. The cost of wind energy is lowest compared to other renewable sources. The paper has been found from the studies, the current average capital cost for wind farms is 2.5 million $AU/MW. This cost relatively higher compared to the other overseas areas such as USA and Europe. This price increase is caused by Australia's slower growth in wind power than other overseas sites and as a consequence there are no turbine manufacturers in Australia and most turbine components are imported from overseas. As to supply 4380 MW, assuming 30% capacity factor, it is required the construction of an additional 14,600 MW of wind turbines and total investment for the proposed 14,600 MW wind turbines is estimated at 36,500 million $AU. The operating cost for electricity generation from wind sources is cheap and efficient; hence the uses of this source are increasing rapidly in generating electricity all over the world and presently average growth per annum is 30%–40% [1,45–47]. The cost of installation for the both of wind turbines and solar PV panels are estimated and verified using HOMER software [48]. HOMER software can be used to compare different combinations of component sizes and quantities. This system helps to determine how variable sources such as solar and wind can be optimally integrated into hybrid electrical power systems. It can be determined the economic feasibility of a hybrid energy system, optimized the system design and allowed users to really understand how hybrid renewable systems are worked. It has been explored how variations in resource availability and system costs affect the cost of installing and operation different system designs. In the simulation results many technical and economic details about each system configuration were simulated by HOMER. It is adjusted when system has excess energy and is gone to waste, by adding required batteries to store and then to supply into the system. The example of such system is shown in Fig. 7. There are multiple technology options for the system components are taken as wind turbine 100 kW, PV array 100 kW, Battery 25 surrette 4 KS25P, Inverter 100 kW and Rectifier 100 kW.

HOMER simulates different system configurations using providing inputs and generates results by net present cost which can be used to compare system design options. There are shown overall optimization results consisting four system combinations which are found to feasible as shown in Table 5. The combinations of components are listed in order (from bottom to top) of least cost effective to most cost effective. The cost effectiveness for a system combination is based on system's net present cost. It is assumed in this example; a grid typically serves a small load in an area of Rockhampton. It is necessary to find out whether it makes sense to add wind turbines and PV panels to such system. HOMER displays the categorized optimization results in Table 5. It is seen that grid with wind is the optimal system type and more cost effective than the other systems. The optimization result depends in the price of electrical energy and on the annual average wind speed. In this case annual average wind speed is 5.65 m/s. When annual wind speed is become lower, then the system designs that include wind turbines are no longer optimal. The results for this system are shown in Table 6. For the given inputs mentioned in schematic diagram of Fig. 7 the monthly average energy production and cash flow summary for the most cost effective combination results (grid with wind turbines) are shown in Figs. 8 and 9, respectively.

The combination of grid with wind turbine as shown in Fig. 8, the electricity generation from wind source dominates the electricity supply system with superior wind data and the present cost of wind turbine is lower than grid system as shown Fig. 9. This system is more cost effective but it is not reliable as the system does not have alternative renewable source. When any seasonal variation affects the system, then the system design including wind turbine cannot be optimal no longer. The second

**Table 5**
Overall optimization results of HOMER.

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

| | PV (kW) | FL100 | S4KS25P | Conv. (kW) | Grid (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 25 | 10... | 100 | $ 361,250 | 38,581 | $ 854,447 | 0.183 | 0.62 |
| | | | 25 | 10... | 100 | $ 111,250 | 74,073 | $ 1,058,145 | 0.227 | 0.00 |
| | 100 | 1 | 25 | 10... | 100 | $ 720,250 | 33,824 | $ 1,152,635 | 0.247 | 0.73 |
| | 100 | | 25 | 10... | 100 | $ 470,250 | 64,300 | $ 1,292,217 | 0.277 | 0.20 |

**Table 6**
The cost summary for the most cost effective system (grid with wind turbines).

| Systems | Capacity (kW) | Total net present cost ($) | Operating cost ($/yr) | Levelized cost of energy ($/kW h) |
|---|---|---|---|---|
| Wind | 100 | 854,447 | 38,581 | 0.183 |
| Grid | 100 | | | |

**Table 7**
The cost summary for the third cost effective system (grid with wind turbines and PV panels).

| Systems | Capacity (kW) | Total net present cost ($) | Operating cost ($/yr) | Levelized cost of energy ($/kW h) |
|---|---|---|---|---|
| Wind | 100 | 1,152,635 | 33,824 | 0.247 |
| Grid | 100 | | | |
| PV | 100 | | | |

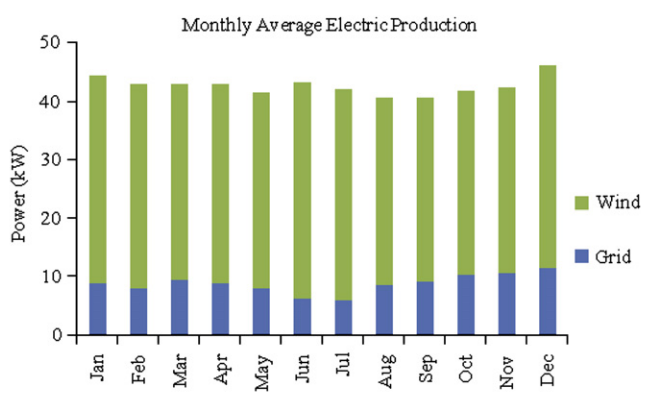


**Fig. 8.** The monthly average electricity production of a typical grid with wind turbine using HOMER software.

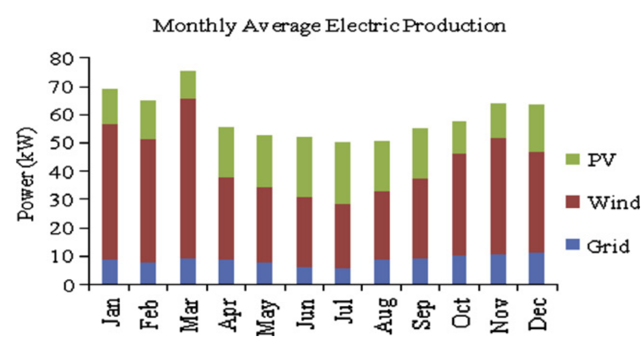


**Fig. 10.** The monthly average electricity production of a typical grid with wind and PV system using HOMER software.

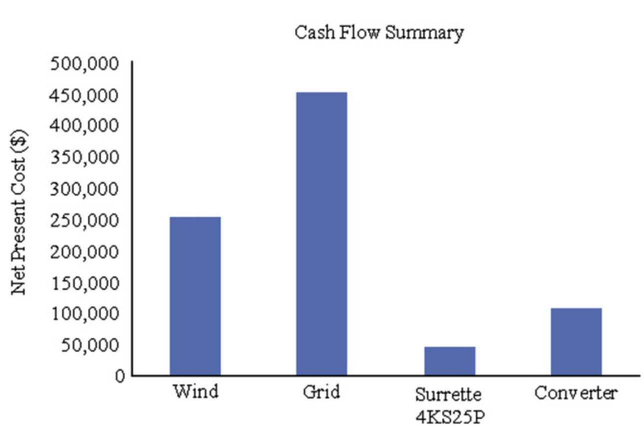


**Fig. 9.** The cash flow summary of a typical Grid with Wind turbine system using HOMER software.

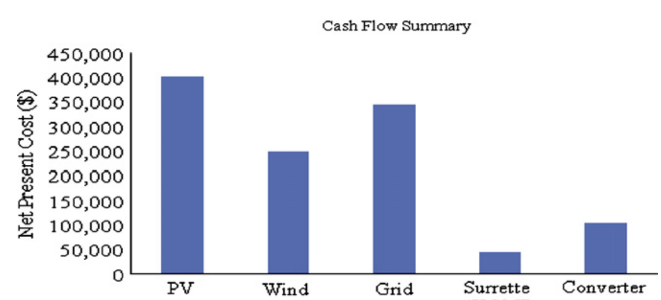


**Fig. 11.** The cash flow summary of a typical grid with wind and PV systems using HOMER software.

cost effective system is shown in Table 5 is grid with battery. But this system is without renewable sources and here it is not considered as renewable fraction is zero. The third cost effective system is grid with wind and PV panels as shown in Table 5. The results for this system are shown in Table 7. For the given inputs mentioned in schematic diagram of Fig. 7 the monthly average energy production and cash flow summary for the third cost effective combination results (grid with wind turbines and PV in Table 5) are shown in Figs. 10 and 11, respectively. The combination of grid with wind turbine and PV panels, the wind turbine dominates the whole system in generating electricity. This system is more reliable because it can contribute in continuous power supply as system designs have alternative renewable source. Here present cost of PV panels is higher than other system as shown in Fig. 11.

In Table 5, even it is third cost effective combination but this combination is very important to continuous power supply for 24 h.

Renewable energy sources are intermittent character, for this reason it is necessary to select technology mix to ensure reliable 24-h energy supply.

The forth cost effective system is grid with PV panels as shown in Table 5. The results for this system are shown in Table 8:

For the given inputs mentioned in schematic diagram of Fig. 7 the monthly average energy production and cash flow summary for the forth cost effective combination results (grid with PV) are shown in Figs.12 and 13, respectively. In case of grid with PV panels as shown in Fig.12, the PV panel source dominates in generating electricity with the superior solar insolation and the present cost of PV panels is lower than the grid as shown in Fig. 13.

**Table 8**
The cost summary for the forth cost effective system (grid with PV panels).

| Systems | Capacity (kW) | Total net present cost ($) | Operating cost ($/yr) | Levelized cost of energy ($/kW h) |
|---|---|---|---|---|
| Grid | 100 | 1,292,217 | 64,300 | 0.277 |
| PV | 100 | | | |

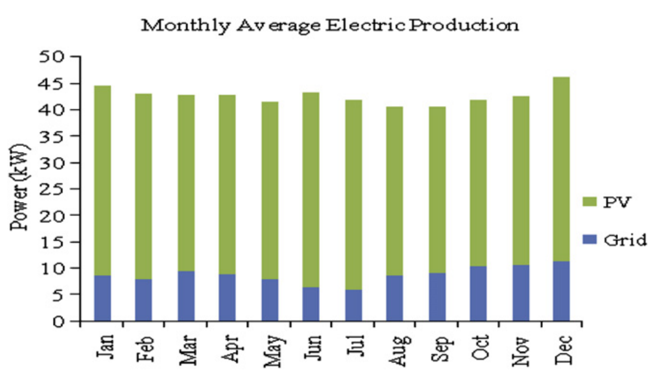


**Fig. 12.** The monthly average electricity production of a typical Grid with PV system using HOMER software.

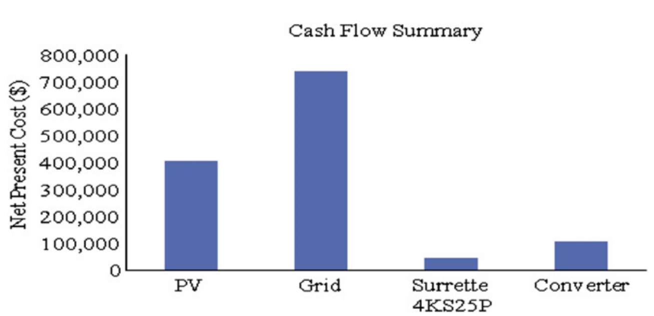


**Fig. 13.** The cash flow summary of a typical grid with PV system using HOMER software.

**Table 9**
Estimated cost of proposed electricity generation from renewable sources.

| Sources | Estimated costs/MW (in million AUD $) | Total Energy in MW | Estimated total costs (in million AUD $) |
|---|---|---|---|
| Wind Turbine | 2.5 | 14,600 | 36,500 |
| Solar PV panels | 3.59 | 2,235 | 8,023.65 |
| | Total estimated cost | | 44,524 |

From the study, it can be estimated total cost of proposed electricity generation from wind turbines and solar PV panels which is shown in Table 9 [44,45].

### 3.4. Environmental impact of electricity generation from renewable sources

About 28 billion tonnes of $CO_2$ are injected into the atmosphere from burning fossil fuels globally in every year [1]. The main advantage in generating electricity from renewable sources is that these sources contribute to reduce $CO_2$ released to the atmosphere. A typical 2 MW wind turbine can be expected to produce over 6000 MW h of electricity in Australia each year and if this replaces coal-fired power, then the $CO_2$ released to the atmosphere will be reduced by 6000 t each year, if it replaces oil or gas-fired power, $CO_2$ released each year is reduced by about 3000 t [33]. Therefore, 14,600 MW wind turbine and 2,235 MW PV panels will contribute in reducing 43.8 million tonnes and 6.705 million tonnes $CO_2$, respectively each year if these replaces coal-fired power and when this replaces oil or gas fired power, then $CO_2$ released each year is reduced by about 21.9 million tonnes and 3.3525 million tonnes, respectively.

### 3.5. Technologies of electricity generation for renewable sources

Australia has many sites of high quality of renewable sources for generating electrical energy. The renewable energy sources are intermittent character because the flow of water does not always constant due to the environmental variation, wind does not always blow and the sun does not shine at night. For this reason, it is necessary to choose technology mix for generation of electrical energy from renewable sources. Wind and solar energy has experienced strong growth over recent years and day by day the application of these sources is increasing all over the world. Due to the higher solar irradiation and wind data in many areas of Australia, these sources can ensure reliable, 24 h electrical energy supply.

### 3.6. Impact of integration for additional electrical energy from renewable sources into the power grid

The existing electrical transmission and distribution system of Australia is not so modern compared to USA and Europe. If about 11.1% additional of total electrical energy is generated and needed to be integrated into the existing power grid, then the system may not be able to carry additional energy due to the limited rating of switchgear and other auxiliary equipments of the power system. The government as well as other related organizations are being worked to solve this burning issue. So with the increasing of electrical energy from wind and solar PV sources, it is necessary to extend the existing capacity of the electrical power transmission and distribution system. It is seen from the study, the 'ZCA2020 Energy plan' proposed a comprehensive upgrade to Australia's electricity grid to allow 100% utilization of the distributed renewable energy network [1]. Three main grids (viz. NEM, SWIS and NWIS) have been proposed across Australia that supply electrical energy to consumers to form one single national grid. The modification of a new national grid will ensure the supply of 100% renewable energy more economical into the future. The new power grid should be able to transmit of additional electrical power from solar and wind sources as well as upgrade connections within the existing grids to provide resilience and reinforcement. The total investment of this upgrade is estimated about 92 billion $ AU [1].

## 4. Conclusion

Renewable energy is now important essential parts of electrical power system which can generate electricity and at the same time reduce thousands of tonnes carbon dioxide emissions. Based on the above discussion, the following conclusions are made:

1. This paper proposed to generate 4827 MW additional electrical energy from wind and solar PV sources that will ensure the government's renewable energy target. The government's target is that 20% of Australia's electricity comes from renewable sources by 2020. This achievement of the target will depend on strong economic conditions.
2. The proposed electricity generation from renewable sources will contribute to reduce 50.505 million tonnes $CO_2$ emission each year if these replace coal fired power and when these replace oil or gas fired power, then $CO_2$ released each year is reduced about 25.2525 million tonnes.
3. The proposed electricity generation from renewable sources will increase the reliability and efficiency of the electrical power system.
4. It is anticipated extensive grid renewal to overcome existing capacity constraints.

Policies that will develop and may change further as per requirement to allow 100% utilization of the renewable energy network.

## References

[1] Wright M, Hearps P, Zero carbon Australia stationary energy plan, Australian Sustainable Energy, Melbourne Energy Institute University of Melbourne, July 2010.
[2] Potter CW, et al., Building a smarter smart grid through better renewable energy information, Institute of Electrical and Electronics Engineers, 2009.
[3] Lu, J, et al., Research on smart grid in China, IEEE T&D Asia 2009.
[4] Cuevas-Cubria, C, et al., Energy in Australia 2011, ABARES, department of resources, energy and tourism, Canberra, ACT 2601, Australia 2011.
[5] Cuevas-Cubria C et al., Energy in Australia 2010, ABARE, department of resources, energy and tourism, Canberra, ACT 2601, Australia, 2010.
[6] Logica, 2009 Smart grid study, Australia.
[7] Miah MS, et al. Optimum policy for integration of renewable energy sources into the power generation system,. Elsevier, Energy Economics 2012;34: 558–67.
[8] Krajačić G, et al. Planning for a 100% independent energy system based on smart energy storage for integration of renewables and CO2 emissions reduction,. Elsevier, Applied Thermal Engineering September, 2011;31: 2073–83.
[9] Curran G. Contested energy futures: shaping renewable energy narratives in Australia,. Elsevier, Global Environmental Change February, 2012;22:236–44.
[10] Liao C, et al. Wind power development and policies in China,. Elsevier, Renewable Energy 2010;35:1879–86.
[11] Kanase-Patil AB, et al. Integrated renewable energy systems for off grid rural electrification of remote area,,. Elsevier Renewable Energy 2010;35:1342–9.
[12] Olofsson M, Power quality and EMC in smart grid, 10th international conference, electrical power quality and utilization, Sept. 15–17, 2009, Lodz, Poland., 2009.
[13] Michalena E, Hills JM. Renewable energy issues and implementation of European energy policy: the missing generation,. Elsevier, Energy Policy June, 2012;45:201–16.
[14] Wüstenhagen R, Menichetti E. Strategic choices for renewable energy investment: conceptual framework and opportunities for further research,. Energy Policy 2011.
[15] Yusaf T, et al. Potential of renewable energy alternatives in Australia,. Elsevier, Renewable and Sustainable Energy Reviews 2011;15:2214–21.
[16] Nasiri A, Integrating energy storage with renewable energy systems, Institute of Electrical and Electronics Engineers, 2008.
[17] Kmau JN, et al. 6 years of wind data for Marsabit, Kenya average over 14 m/s at 100 m hub height: an analysis of the wind energy potential,. Elsevier, Renewable Energy 2010;35:1298–302.
[18] Lohan SK, et al. Resource potential and scope of utilization of renewable energy in Jammu and Kashmir, India,. Elsevier, Renewable Energy March 2012;39:24–9.
[19] Praene JP, et al. Renewable energy: progressing towards a net zero energy island, the case of Reunion Island,. Renewable and Sustainable Energy Reviews 2011.
[20] Richards G, et al. Barriers to renewable energy development: a case study of large-scale wind energy in Saskatchewan, Canada,. Elsevier, Energy Policy 2012;42:691–8.
[21] Romero SR, et al. EU plans for renewable energy. An application to the Spanish case,. Elsevier, Renewable Energy July, 2012;43:322–30.
[22] Trappey AJC, et al. The analysis of renewable energy policies for the Taiwan Penghu island administrative region,. Renewable and Sustainable Energy Reviews 2011.
[23] Katinas V, et al. Governmental policy and prospect in electricity production from renewables in Lithuania,. Energy Policy 2008;36:3686–91.
[24] Erdinc O, Uzunoglu M. Optimum design of hybrid renewable energy systems: overview of different approaches,. Elsevier, Renewable and Sustainable Energy Reviews 2012;16:1412–25.
[25] Consulting R, Additional projections of electricity generation in Australia to 2050, supplementary report, A.B.N. 54 091 533 621, September, 2011.
[26] SC, et al., Major electricity generation projects, Bureau of resources and energy economics, Canberra, November 2011.
[27] Hamed T Abu, et al. Renewable energy in the Palestinian territories: opportunities and challenges,. Renewable and Sustainable Energy Reviews 2011.
[28] 〈http://forums.whirlpool.net.au/archive/1781018〉 -150 GW installed capacity,- Green Tech.
[29] 〈http://www.bom.gov.au/climate/data/〉, Bureau of meteorology, Australian Government .
[30] Hammons TJ. Integrating renewable energy into European grid,. International Journal of Electrical Power Energy Systems October 2008;30:462–75.
[31] 〈http://www.wordl-nuclear.org/info/inf64.html〉.- Australia's Electricity.
[32] 〈http://www.climatechange.gov.au/what〉 -you-need- to know/renewable-energy. asps.-Renewable energy-Think change .
[33] 〈http://ramblingsdc.net/Australia/WindPower.html〉.
[34] Lanzafame R, Messina M. Horizontal axis wind turbine working at maximum power coefficient continuously. Elseevier, Renewable Energy 2010;35:301–6.
[35] Kesraoui M, et al. Maximum power point tracker of wind energy conversion system,. Elseevier, Renewable Energy 2011;36:2655–62.
[36] Knoll A, Klink K. Residential- and commercial—scale distributed wind energy in North Dakota, USA,. Elseevier, Renewable Energy 2009;34:2493–500.
[37] Taibia E, et al. The potential for renewable energy in industrial applications,. Elseevier, Renewable and Sustainable Energy Reviews 2012;16:735–44.
[38] Ibrahim A. Renewable energy sources in the Egyptian electricity market: a review Elsevier, Renewable and Sustainable Energy Reviews 2012;16: 216–30.
[39] Diana M. Romania's energy potential of renewable energies in the context of sustainable development,. Annals of Faculty of Economics 2011;1:176–80.
[40] 〈http://www.accc gov.au/content/item.phtml?〉item Id+…-Electricity Generation.
[41] Prasad DK Snow M, Example of successful architectural integration of PV: Australia, prog. Photovoltaic: Research & Application, 447–483 (DOI: 10.1002/pip 527) 2004.
[42] 〈http://en.wikipedia.org/wiki/Capacity_factor〉.
[43] Dupraz C, et al. Combining solar photovoltaic panels and food crop for optimising land use: towards new agrivoltaic schemes,. Elseevier, Renewable Energy 2011;36:2725–32.
[44] 〈http://www.au.bestprice.com/search/landing/winding+turbine/s/google/ev/1209407〉.
[45] 〈http://www.solarbuzz.com/ModulePrices.htm〉+.
[46] Smart networks position paper Energy network association, published by the energy networks association, level 3, 40 Blackall Street, Barton ACT 2600, Australia, September 2009.
[47] Mezher T, et al. Renewable energy policy options for Abu Dhabi: drivers and barriers,. Energy Policy 2011.
[48] 〈http://www.homerenergy.com/〉.

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Received 13 May 2011

Available online 7 September 2012

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